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# Advances in Physical Science Research

## Bio-Chemical Sensor Based on Square Ring and Circular Ring Photonic Crystal Ring Resonator

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### Abstract

In this paper we have presented two photonic crystal ring resonator structures for application as a bio-chemical sensor. One is based on square ring and the other is based on circular ring. The refractive index of square ring and circular ring situated in the center of these structures has been varied according to the refractive index of the materials which has to be sensed. The resonant output peaks of both the square ring and circular ring structure are compared and it has been tried to determine which type of structure among the two is more suitable to be taken for use as a bio-chemical sensor. Simulation is done by applying finite-difference time domain (FDTD) and planar wave expansion (PWE) method.

**Keywords:** Photonic crystal; Ring resonator; Finite difference time domain; Plane wave expansion.

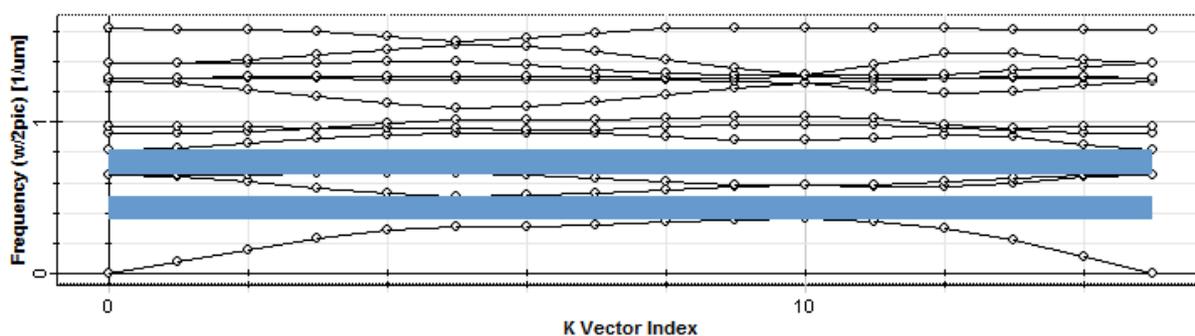
### 1. Introduction

Photonic Crystals (PC) have proved to be very suitable candidates for application in optical devices. PC based optical devices are compact in size, provide high speed of operation and have long-life. PC could be arranged in one two or three dimensions according to the application of the structure required. We have concentrated our efforts on 2-dimensional PC structures, since it can have more applications than 1-dimensional structure and more feasible to simulate than the 3-dimensional structure. Based on 2-dimensional PC structure many optical devices are proposed and analyzed in recent years for instance optical switches [1], band-pass filters [2], add-drop filters [3,4], multiplexers [5], bio-sensors [6] etc. We have presented two photonic crystal ring resonator (PCRR) structures [7] and compared them for application in sensing purpose. One PCRR consists of a square ring while the other consists of a circular ring.

## 2. Structure Design

The basic structure of PCRR consists of silica rods arranged in a 2-dimensional lattice. The refractive index of silica rods is chosen to be 4.15 and their radius is kept to be  $0.165 \mu\text{m}$ . The lattice constant 'a', which is the distance between two silica rods is made to be  $0.615 \mu\text{m}$ . The whole structure consists of  $25 \times 29$  rods of silica.

Plane wave expansion (PWE) method [8] has been applied to calculate the bandgap of the structure. Two bandgaps have been generated as shown in Fig.1. We have focused on the first bandgap visible in the figure, starting from the downwards direction as it encompasses widely preferred communication wavelength also i.e.  $1.55 \mu\text{m}$ .



**Fig.1.** Band diagram of  $25 \times 29$  rectangular lattice.

After simulation of the structure for the bandgap, silica rods have been eliminated from the center of the structure to form a cavity. In this cavity square and circular rings made again of silica rods are introduced to form two new structures as shown in Fig. 2 and Fig. 3 respectively. The square and circular rings are made such that they both contain equal number of rods and they have same area enclosed. The reason for this is we can compare both the structures for confinement of modes in similar area.

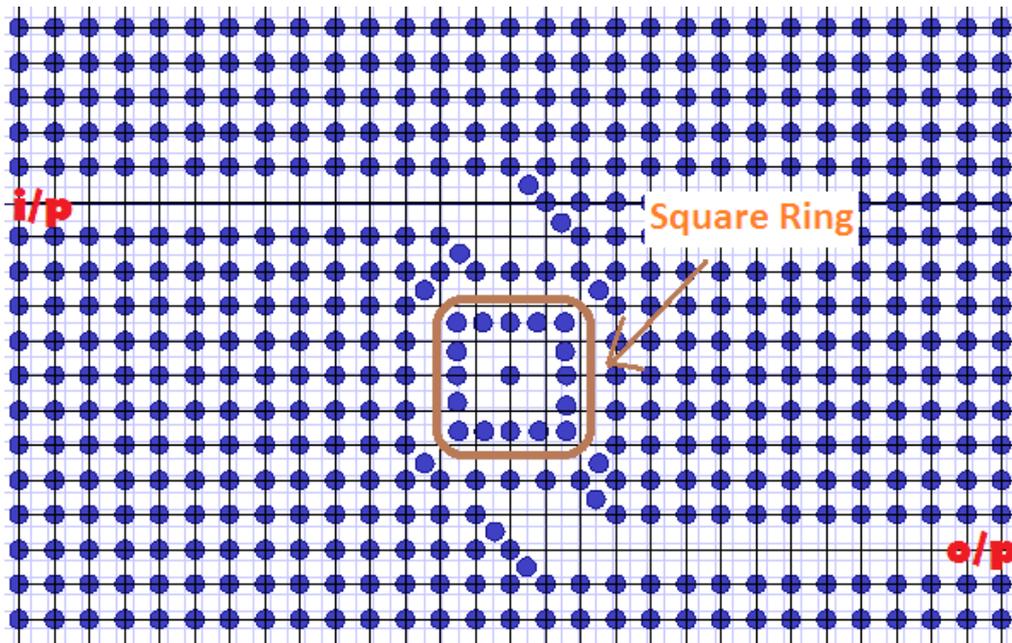


Fig. 2. The schematic diagram of proposed filter with square resonant ring.

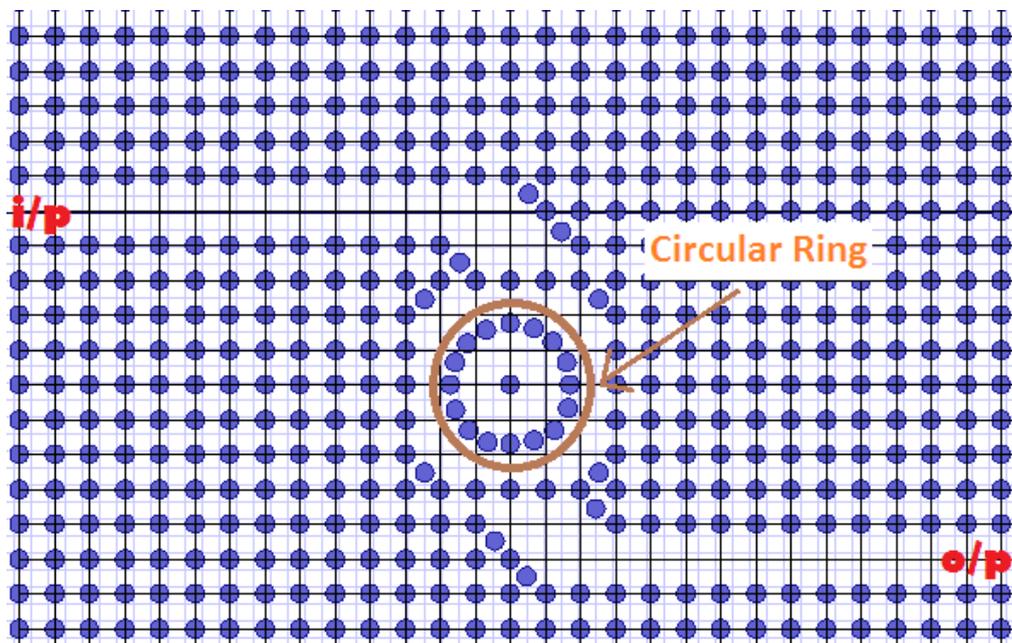


Fig. 3. The schematic diagram of proposed filter with circular resonant ring.

### 3. Results and Discussion

Finite-difference time-domain (FDTD) [9,10] technique with perfectly matching layer (PML) [11] absorbing boundary conditions has been used to simulate the ring resonator structures.

We have varied the refractive index of inner rods of the cavity in both square ring structure as

well as circular ring structure. The refractive index is varied from 2.2 to 2.28 with an interval

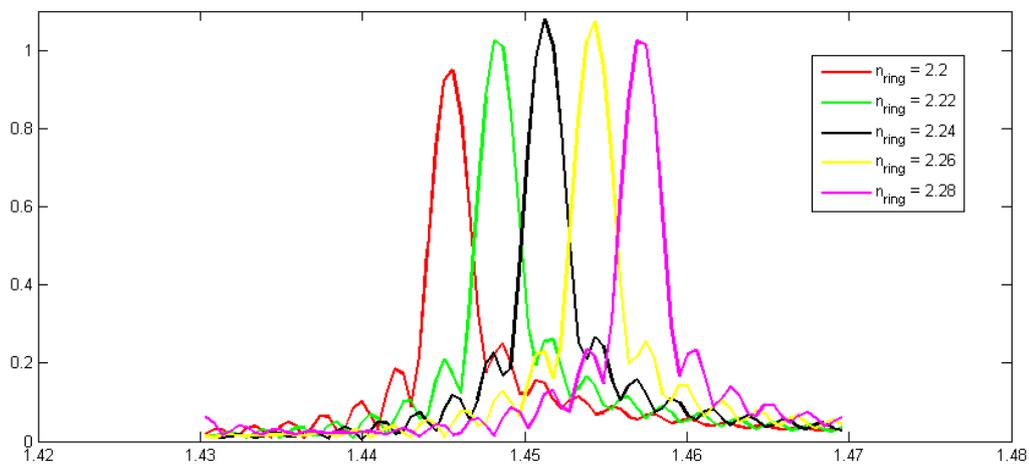
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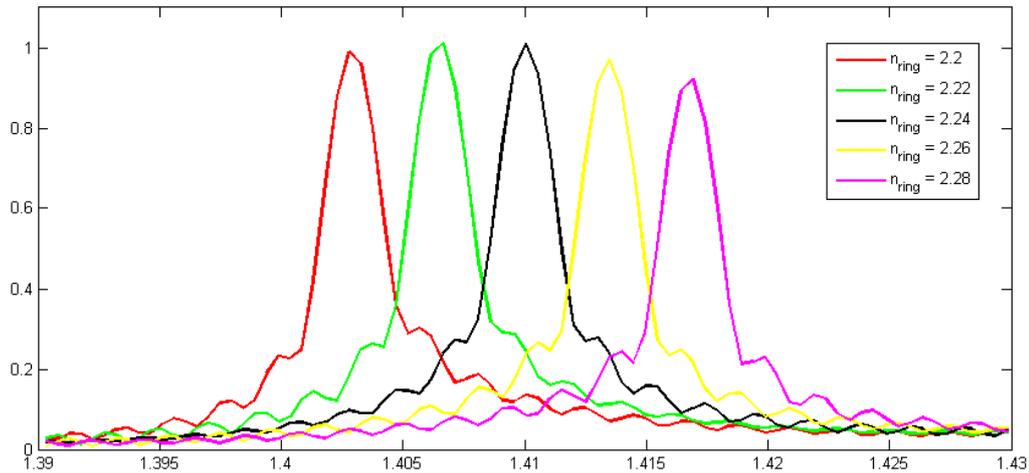
of 0.02. A Gaussian pulse has been made to fall at the input end of the photonic crystal structures with half-width of 0.5  $\mu\text{m}$  and amplitude equal to 1.0 V/m. An observation point is fixed at the output to detect the resonance peak. For square ring structure we observe the output peaks as shown in Fig.4. The figure shows, as we increase the refractive index of inner rods, the peak keeps shifting rightwards in the increasing direction of the wavelength. Considering the output of circular ring structure, as seen in Fig.5, we observe nearly same results as compared to that of the square ring. The major difference is, the starting peak (corresponding to 'n' of inner ring=2.2) is shifted in the left direction in circular ring structure by about 42 nm on wavelength scale. Rest both the structures have similar output resonant peaks. Talking about the quality factor Q, which is given by the equation below:

$$Q = \lambda_0 / \Delta\lambda \quad (1)$$

Here,  $\lambda_0$  is the wavelength of the resonant peak point and  $\Delta\lambda$  is the full-width half maxima of the same peak. The value of Q comes out to be nearly 485 taken as average of the 4 peaks of the square ring structure and also for the circular ring structure. This value of Q is high enough for optimum result.



**Fig.4.** Normalized transmission spectra of square ring structure



**Fig.5.** Normalized transmission spectra of circular ring structure

#### 4. Conclusion

Two structures are proposed based on square ring and circular ring in the cavity of photonic crystal structure for application as bio-sensor. Output of both the structures are studied by inserting materials of different refractive index on the inner rods. It has been observed that both the structures have the same sensing properties. Only difference is the resonant wavelength output is shifted in left direction in circular ring structure as compared to square ring structure. Hence we can say a high sensitivity bio-chemical sensor has been studied based on square and circular ring respectively. Future work include the variation of refractive index of coupling rods according to the materials need to be sensed.

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